Research Paper

Research on the Coupling Coordination Degree of Land Intensive Use and Sustainable Development in Shrinking Cities

A Case Study of Northeast China

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Abstract

In China, the phenomenon of shrinking cities is primarily manifested by the outflow of production factors, including population, capital, and enterprises. Simultaneously, these cities continue to develop according to growth-oriented planning concepts, posing significant challenges to the sustainable and high-quality development of urban density.

This study focuses on Northeast China as an empirical case. First, an evaluation system for the degree of land intensive use is established, utilizing the entropy method to assess the spatial distribution characteristics of land intensive use in shrinking cities. Second, factor analysis is employed to evaluate the sustainable development levels of these cities, as well as their temporal and spatial variations. Finally, the coupling coordination degree model is applied to analyze the temporal and spatial differentiation patterns of the coupling coordination degree between land intensive use and sustainable development in shrinking cities.

The findings indicate a high degree of consistency between the pattern of land intensive use in Northeast China and the spatial distribution of identified shrinking cities. There exists a strong temporal and spatial coupling relationship between land intensive use and sustainable development in these cities, with the overall situation currently positioned in a transitional phase towards coupled coordination.

Keywords

Land intensive use, Sustainable development, Shrinking city, Northeast China

1. Introduction

Urban shrinkage, a growing research focus, has emerged globally with unique characteristics in China. While often driven by globalization, deindustrialization, and suburbanization in Western contexts, China's shrinkage is largely due to resource depletion and industrial restructuring, leading to population and capital outflows. Despite population loss, cities maintain a growth-oriented land expansion model, resulting in inefficient land use and vacancy issues, which challenges sustainable urban density.

Addressing these challenges, China's 2014 Guiding Opinions on Promoting Economical and Intensive Land Use aimed to regulate land use and improve land management quality, making progress (The Ministry of Land and Resources, 2014). However, urban construction land increased by over 26% between 2010 and 2020, with a 14% rise in urbanization (China Urban-Rural Construction Statistical Yearbook, 2020), leaving significant underutilized land, particularly in shrinking cities. Studies show a reciprocal influence between land use intensity and urban economic, social, and environmental systems, significantly impacting sustainable urban development.

This study investigates intensive land use in shrinking cities, focusing on the coupling relationship between land use intensity and sustainable development to illustrate land intensification's role in promoting sustainability and to provide insights for spatial planning and sustainable development strategies in shrinking cities.

2. Literature Review

The concept of sustainable development emerged in 1980 with the World Conservation Strategy (Purvis, Mao, and Robinson, 2019) and was further defined as a city framework where economic growth, quality of life, and ecological sustainability coexist (Zovanyi, 2009). Scholars have since developed multi-dimensional indicators to assess sustainable development at various levels, incorporating factors such as population, resources, economy, and society. For instance, An et al. used 19 ecological and economic indicators to evaluate regional sustainability in China (An et al., 2022); Salvati and Carlucci selected 99 variables for Italian cities (Salvati and Carlucci, 2014); and Strezov et al. used nine global indices (Strezov, Evans, and Evans, 2017). Popular evaluation methods include AHP (Fu, Li, and Li, 2014), Entropy (Wang et al., 2022), and PLS-SEM (Li and Long, 2020).

The concept of intensive land use, originally from agricultural rent theories by Ricardo, has evolved to address urban and industrial land efficiency (Lu et al., 2012). Intensive land use aims for high output on smaller areas using concentrated inputs and advanced management (Genga, Zheng, and Fu, 2017). Research has explored various facets: theoretical models like “compact development” align with China’s land use goals (Burchell, Listokin, and Galley, 2000); evaluation approaches include multi-dimensional systems and models like DEA, SFA, and Neural Networks. Studies also investigate the interaction of land use with urbanization and economic factors (Dai and Sh, 2023; Hoole, Hincks, and Rae, 2019; Zhou and Yao, 2024), though further exploration is needed on its coupling with sustainable development.

3. Research Methods and Data Sources

3.1 Research Methods

(1) Entropy Method

The Entropy Method is a multi-indicator weight calculation method based on information entropy theory, used to determine the importance weight of each indicator in a comprehensive evaluation. The core concept involves calculating the information entropy of each indicator to assess its dispersion level and, accordingly, determine its weight. In this study, the Entropy Method is applied to calculate the weights of various indicators for urban land intensive use and sustainable development. First, the raw data of each indicator (x_{ij}) is normalized using the extreme value method to obtain standardized values (x_{ij}), followed by applying the variation coefficient method from objective weighting methods to determine the weights (Bandt and Pompe, 2002).

Data Standardization: Since the measurement units and directions of the indicators may vary, data standardization is required.

$$x_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{1}$$

x_{ij}represents the value of sample i under indicator j.

$$P_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}} \tag{2}$$

P_{ij}represents the value of sample i after normalization under indicator j.

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \tag{3}$$

$e_j$denotes the information entropy of indicator j, where k is a constant, generally set to $\mathrm{k} = \frac{1}{\ln(\mathrm{n})}$

$$g_j = 1 - e_j \tag{4}$$

The greater the difference in data, the greater the weight of its indicators

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{5}$$

In the formula, $w_j$represents the weight of indicator j.

(2) Coupling Coordination Degree Model

U_1 represents the degree of intensive land use, U_2 represents the level of sustainable development, C represents the coupling degree between the two, D represents the coupling coordination between the two, and α and β are debugging parameters. This study believes that the level of land intensive use and sustainable development in cities are equally important, therefore both coefficients are set as $\alpha = \beta = 0.5$. According to relevant literature, $(0 \leq \mathrm{C} < 0.3)$ is the low coupling stage, $(0.3 \leq \mathrm{C} < 0.5)$ is the antagonistic stage, $(0.5 \leq \mathrm{C} < 0.8)$ is the break in stage, and$(0.8 \leq \mathrm{C} < 1.0)$ is the high coupling stage (Li et al., 2012).

$$D = \sqrt{C \times T} = \left[U_1 \times U_2 / \left(\frac{U_1 + U_2}{2}\right)^2 \times (\alpha \times U_1 + \beta \times U_2)^{1/2}\right] \tag{6}$$

3.2 Construction of the Evaluation System and Indicator Selection

From the perspective of resource constraints and sustainable development, this study constructs an evaluation indicator system based on the principles of comprehensiveness, scientific rigor, systematicity, and operability. Drawing on existing literature and the "input-output" theoretical framework, the system primarily considers land use intensity, input-output efficiency, and sustainability. The Entropy Method is then applied to conduct a multi-dimensional information integration for a comprehensive assessment of land intensification levels. As shown in Table 1, population density and the proportion of construction land area represent land's population carrying capacity and total usage from different perspectives. Fixed asset investment per unit of land and the employment in secondary and tertiary industries reflect the economic and human resource inputs in land use. GDP per unit of land and general public budget revenue measure urban economic development efficiency and land use efficiency from an output perspective. Per capita park green space and forest coverage indicate ecological protection and landscape benefits of land development. To ensure data consistency, each indicator is expressed in per capita or per unit land terms to minimize the impact of regional land area differences.

Table 1: Evaluation System for Land Intensive Use Levels. Source: Self Drawing.

Criteria Layer	Indicator Layer	Unit	Indicator Attribute
Land Intensive Use	Population Density	people/km^2	+
	Proportion of Built-Up Land Area	%	+
Land Input Intensity	Fixed Asset Investment per Unit of Land	10,000 CNY/km^2	+
	Labor Input per Unit of Secondary and Tertiary Sectors	people/km^2	+
Land Output Efficiency	GDP per Unit of Land	10,000 CNY/km^2	+
	General Public Budget Revenue	10,000 CNY	+
Land Sustainability Degree	Per Capita Park Green Space Area	m^2/people	+
	Forest Coverage Rate	%	+

Following the principles of authority, universality, reliability, comparability, and operability, this study draws on the SDGs evaluation indicator library, localized SDGs indicators within China, and existing research on urban sustainable development (Godard, 2003). After eliminating duplicate and unreliable indicators, a quantitative multicollinearity test was conducted to prevent redundancy in indicator selection. Ultimately, a framework was constructed around four subsystems—economy, livelihood, resources, and environment—encompassing 11 domains and 11 indicators.

Table 2: Evaluation System for Sustainable Development Levels. Source: Self Drawing.

System	Domain	Specific Indicator	Unit	Corresponding SDG	Attribute
Economic Development	Technological Innovation	Proportion of R&D Expenditure in Public Fiscal Expenditure	%	Goal 9: Innovation	+
	Economic Strength	Per Capita GDP	CNY/person	Goal 8: Economic Growth	+
	Industrial Structure	Tertiary Industry Output as a Proportion of GDP	%	Goal 8: Economic Growth	+

Livelihood and Well-being	Quality of Life	Per Capita Disposable Income	CNY/person	Goal 1: No Poverty	+
	Infrastructure Development	Per Capita Road Area	m^2/person	Goal 9: Resilient Infrastructure for Disaster Response	+
	Population Development	Per Capita Education Expenditure	CNY/person	Goal 4: Quality Education	+
Resource Utilization	Resource Security	Per Capita Daily Water Supply	t/person	Goal 6: Sustainable Water Supply Services	+
	Efficient Resource Use	Energy Output Efficiency	10,000 CNY/t standard coal	Goal 7: Sustainable Modern Energy	+
Environmental Quality	Pollution Control	Environmental Pollution Index		Goal 12: Sustainable Production Patterns	-
	Ecological Status	Green Coverage Rate in Built-up Areas	%	Goal 11: Sustainable Cities	+
	Environmental Management	Safe Disposal Rate of Household Waste	%	Goal 6: Sanitation and Hygiene	+

3.3 Study Area

This study focuses on these three northeastern provinces, excluding the two administrative units of Daxinganling and Yanbian Korean Autonomous Prefecture due to data availability, and involves a study of 34 prefecture-level cities.

In this study, shrinking cities within the three northeastern provinces are defined as administrative units experiencing a decrease in urban population from 2010 to 2020, while others are classified as non-shrinking cities. Population shrinkage rates for each prefecture-level city are calculated based on data from the Chinese Population Census using the following formula:

$$X_i = \frac{(P_{2020} - P_{2010})}{P_{2010}} \times 100\% \tag{7}$$

where P_{2010} represents the urban population from the sixth national population census, P_{2020} represents the urban population from the seventh census, and X_i is the population change rate.

The results indicate that from 2010 to 2020, there were 20 prefecture-level cities in the three northeastern provinces experiencing population shrinkage, accounting for approximately 60% of the region. Among them, the cities of Siping, Yichun, and Baishan had population shrinkage rates exceeding 20%. This demonstrates that population shrinkage in the three northeastern provinces is both widespread and severe in certain cities.

Table 3: List of Shrinking Cities. Source. Self Drawing.

Shrinking Cities	Siping, Yichun, Baishan, Benxi, Qitaihe, Baicheng, Tonghua, Jixi, Hegang, Suihua, Qiqihar, Jilin, Shuangyashan, Mudanjiang, Songyuan, Fushun, Heihe, Liaoyuan
Non-Shrinking Cities	Anshan, Dandong, Liaoyang, Jiamusi, Fuxin, Jinzhou, Harbin, Daqing, Yingkou, Tieling, Panjin, Huludao, Shenyang, Dalian, Chaoyang, Changchun

4. Temporal and Spatial Evolution Characteristics of Land Intensive Use

4.1 Temporal Evolution Characteristics

According to the evaluation methods described above, the levels of land intensive use for the 34 prefecture-level cities in the three northeastern provinces were measured from 2010 to 2020, with the results displayed in the figure below. As shown in Figure X, the temporal evolution of land intensive use levels for these cities initially exhibits an upward trend, followed by a decline. The average level of land intensive use across all cities increased from 0.186 in 2010 to 0.223 in 2013, but fluctuated downward from 2014 to 2020, reaching 0.191. Overall, over the past decade, the region has not experienced significant improvement in land intensive use levels, and issues of extensive land use remain unresolved.Regarding population shrinkage, it is evident that the average land intensive use levels in shrinking cities are significantly lower than those in non-shrinking cities. From 2010 to 2020, the change rate in land intensive use levels for shrinking cities was 0.01%, compared to 0.8% for non-shrinking cities, with instances in which the land intensive use level in 2020 was lower than in 2010. Among the 18 prefecture-level cities experiencing population shrinkage, 10, 12, and 14 cities had land intensive use levels below the overall average in 2010, 2015, and 2020, respectively. This indicates a regressive trend in land intensive use levels over the past decade in shrinking cities. Although land input intensity increased, the efficiency of land output and the sustainability of land use remained suboptimal.

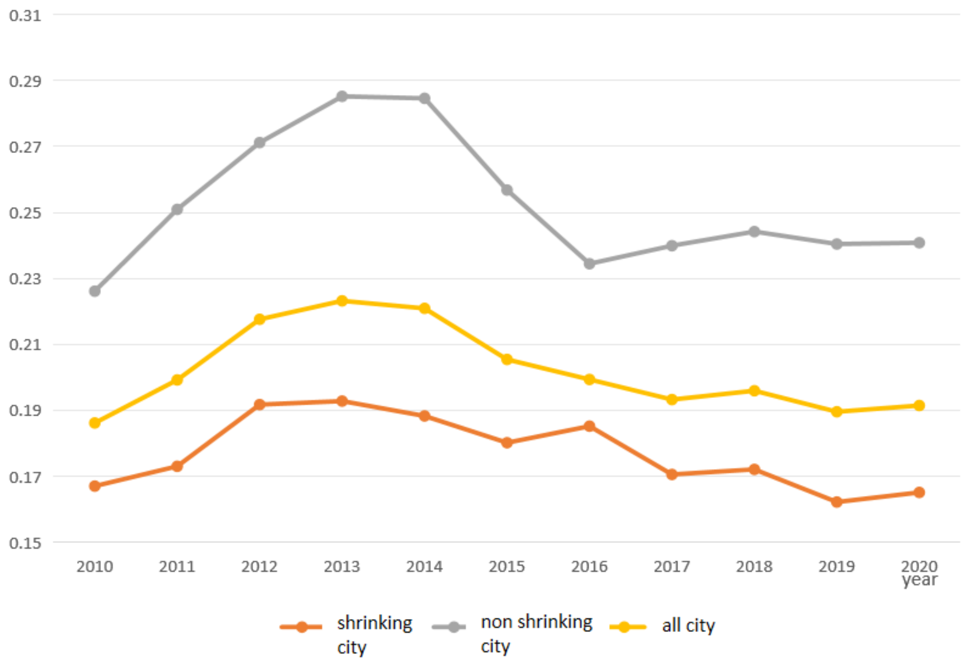

Figure 1: Evaluation Results of Land Intensive Utilization Levels in Northeast China (2010-2020). Source: Self Drawing.

For individual cities, Baicheng, Qiqihar, and Jiamusi are the three cities with the lowest level of land intensive use, with an average of 0.064, 0.075, and 0.076 over the past decade, respectively; Shenyang and Dalian are the two cities with the highest level of land intensive use, with average values of 0.0526 and 0.0532 respectively, far higher than other cities.

4.2 Spatial Evolution Characteristics

To further analyze the spatial differentiation characteristics of land use efficiency in the three provinces of Northeast China, ArcGIS natural break point method was used to classify them into three categories from low to high: low-level zone, general level zone, and high-efficiency zone, and the results were visualized and analyzed. As shown in Figure 2, the areas with high levels of land intensive use in 2010 and 2020 were mainly distributed along the Harbin Dalian axis, exhibiting obvious core periphery characteristics. With the passage of time, the level of intensive land use in the northern border areas has gradually decreased in the region, and has all evolved into low-level areas. In 2020, there was an increase in high-level cities, with three growth poles emerging in Shenyang, Dalian, and Changchun. However, there is a lack of high-level cities in Heilongjiang Province. Overall, the level of land intensive use in the three northeastern provinces shows a phenomenon of high in the south and low in the north, and high in the east and low in the west.

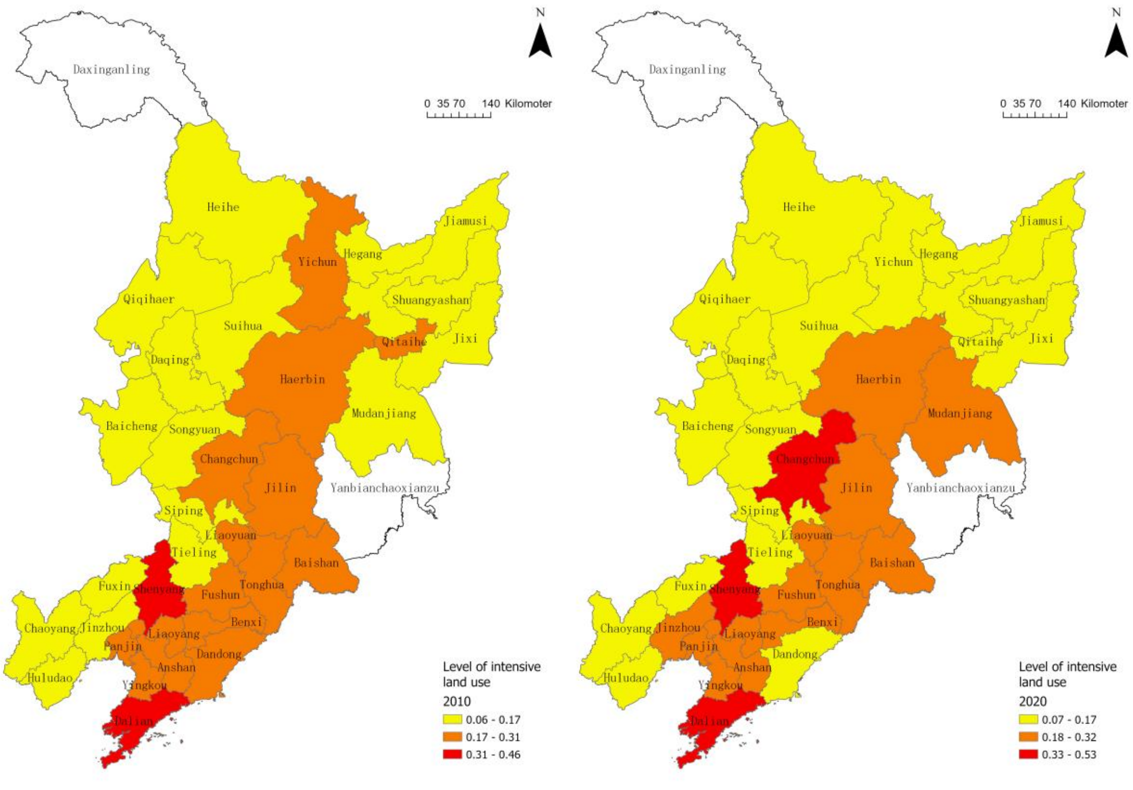

Figure 2: Distribution Pattern of Land Intensive Utilization in Northeast China for the Years 2010, and 2020. Source: Self Drawing.

On the basis of understanding the level of land intensive use in various prefecture level cities, use the "Global Moran's I" in ARCGIS to analyze the global spatial correlation and visualize the results. According to Table 4, the autocorrelation coefficients of land intensive use levels in the three prefecture level cities in Northeast China in 2010, 2015, and 2020 were all positive, and the P-values passed the significance test of 0.5, indicating a significant positive correlation and a significant agglomeration effect in space.

Table 4: Global Spatial Autocorrelation Analysis Results of Land Intensive Utilization in Northeast China. Source: Self Drawing.

Year	Moran's I	z	p
Land Intensive Use Level in 2010	0.305121	3.213665	0.001311
Land Intensive Use Level in 2015	0.276764	2.963194	0.003045
Land Intensive Use Level in 2020	0.212536	2.354618	0.018542

Further analysis of local spatial autocorrelation revealed that the hotspots gradually narrowed in scope, but remained concentrated in the southeastern region of Liaoning Province. The range of cold spots is gradually expanding, forming a "contiguous and extremely impoverished" area in the northeastern border area of Heilongjiang Province, with a few also distributed in Daqing City and Qiqihar City. Overall, the three provinces in Northeast China have formed a spatial pattern of "hot in the south and cold in the north", with hot and cold areas relatively fixed over the past decade.

Shenyang and Dalian occupy prominent central positions within the three northeastern provinces, aggregating resources and development advantages from surrounding cities. As significant growth poles for the region, they exert a strong driving effect, resulting in a marked advantage in the overall allocation and utilization efficiency of land resources in southeastern Liaoning Province. Conversely, the geographical location of the northern border areas is relatively remote. On one hand, an industrial structure primarily based on agriculture and other primary sectors constrains socio-economic development. On the other hand, due to geographical conditions and resource endowments, there is a high proportion of ecological land use, limiting the potential for adequate development and construction. This situation, in turn, hampers the improvement of land intensive use levels.

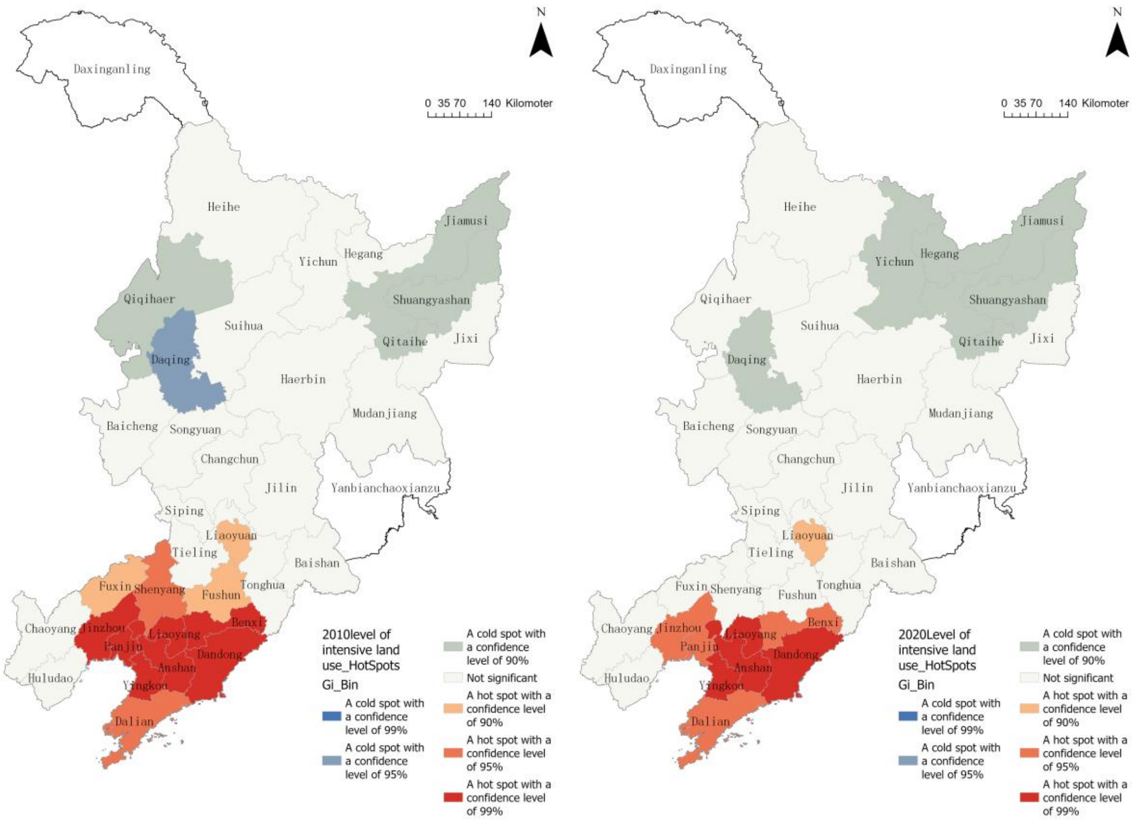

Figure 3: Hotspot Analysis of Land Intensive Utilization in Northeast China for the Years 2010 and 2020. Source: Self Drawing.

5. Temporal and Spatial Evolution Patterns of the Coupling Coordination Degree between Land Intensive Use Level and Sustainable Development

5.1 Temporal Evolution Characteristics

Based on the coupling coordination degree calculation method, this study measures the coupling coordination relationship between land intensive use levels and sustainable development levels in Northeast China from 2010 to 2020.

From a temporal perspective, the coupling coordination degree between land intensive use and sustainable development in Northeast China exhibited fluctuations over the decade, with only a modest increase overall. Between 2010 and 2013, the coupling coordination degree rose from 0.39 to 0.43; however, it declined after 2013, returning to 0.40 in 2020, approximately the same level as in 2010. Over this period, the coupling coordination level remained in the antagonistic stage.The coupling level across prefecture-level cities in Northeast China remained consistently high from 2010 to 2020, sustaining a phase of high coupling. However, coordination was relatively poor, with fluctuations showing an initial increase followed by a decrease, yet consistently remained at a low coordination level. For shrinking cities, the coupling coordination degree was persistently lower than in non-shrinking cities, with fluctuations from 2010 to 2020. During the study period, it increased only slightly from 0.355 to 0.356, with an annual growth rate of merely 0.01%, indicating a low and slow development within the antagonistic stage.Regarding coupling degree, the average value for shrinking cities was 0.973, slightly higher than 0.971 for non-shrinking cities, though the difference was minimal, with both in a high-coupling state. In terms of coordination, shrinking cities had an average of 0.140, significantly lower than the 0.222 average for non-shrinking cities, demonstrating a more pronounced high-coupling, low-coordination pattern. At the city level, Dalian, Harbin, Shenyang, Yingkou, and Changchun had the highest coupling coordination degrees in 2020, reaching the adjustment phase, and all were non-shrinking cities. In contrast, Baicheng, Chaoyang, Fuxin, Heihe, and Shuangyashan had the lowest coupling coordination levels, remaining in the low-coupling phase and were classified as shrinking cities.

Overall, from 2010 to 2020, the coupling coordination between land intensive use and sustainable development in Northeast China remained at a low level, with slow overall progress and a lack of transition from maladjustment and decline to a coordinated coupling stage. The system's coupling degree was significantly higher than its coordination degree, reflecting a persistent imbalance characterized by high coupling but low coordination. This imbalance was especially pronounced in shrinking cities.

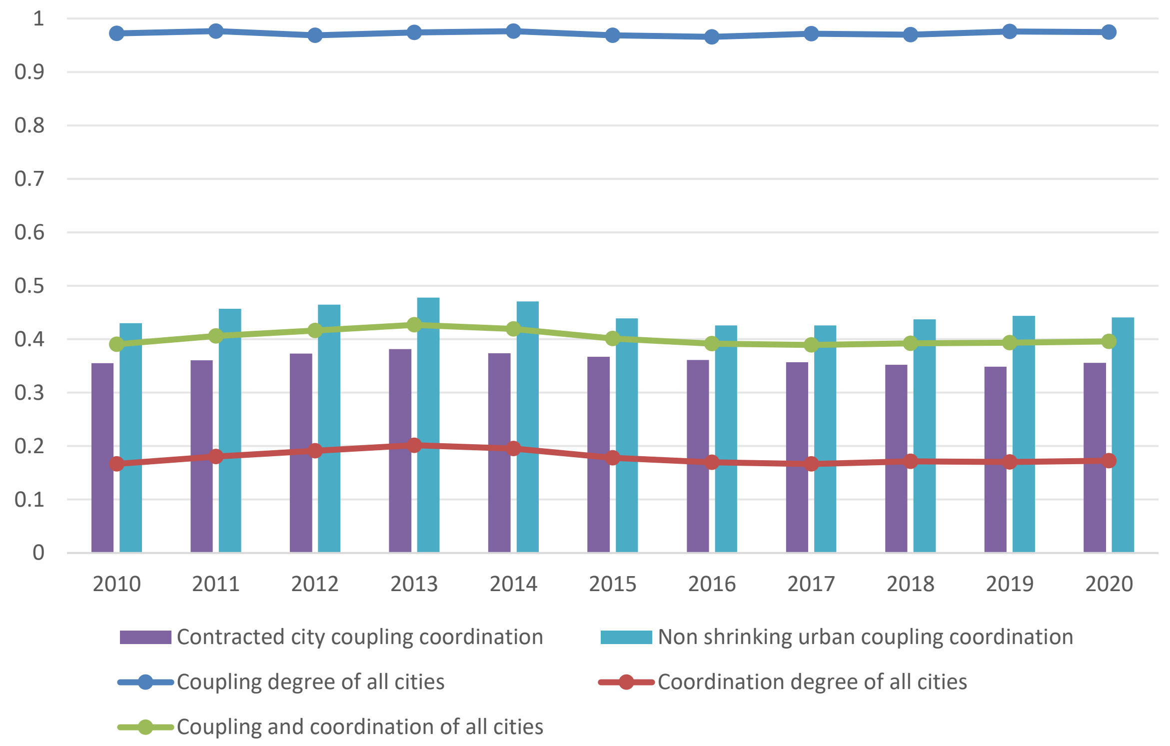

Figure 4: Evaluation Results of Coupling Coordination Degree in Northeast China (2010-2020). Source: Self Drawing.

5.2 Spatial Evolution Characteristics

Based on the coupling coordination degree calculation method, we assessed the coupling coordination relationship between land intensive use levels and sustainable development levels in Northeast China from 2010 to 2020.

As illustrated in the figure, the coupling coordination degree between land intensive use and sustainable development in Northeast China exhibits significant spatial heterogeneity. Cities along the Harbin-Dalian axis generally demonstrate higher coupling coordination degrees, displaying a gradual decrease in coordination levels from the axis towards the east and west, which highlights the prominent "core-periphery" phenomenon. During the study period, the number of cities reaching the coordination stage gradually increased, while the number of cities in the low coupling stage decreased. Notably, the number of cities in the antagonistic stage was the highest, accounting for 74% in 2020. In 2010 a contiguous low coupling area emerged in the northeastern region of the area. Shenyang, Dalian, Changchun, and Harbin were identified as the four cities with the highest coupling coordination degrees, further emphasizing the structural significance of the Harbin-Dalian axis.

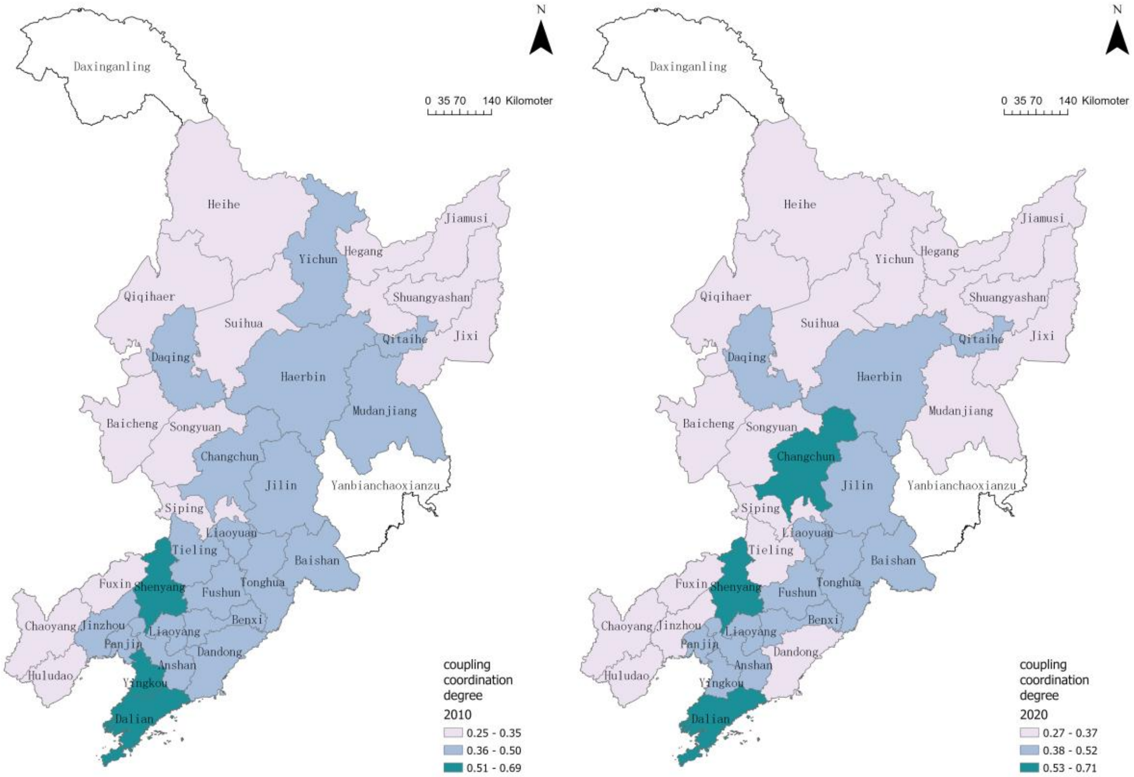

Figure 5: Spatial Patterns of Coupling Coordination Degree in Northeast China for the Years 2010 and 2020. Source: Self Drawing.

Building on the understanding of the coupling coordination degree between land intensive use and sustainable development systems across various prefecture-level cities, we employed the "Global Moran's I" functionality in ArcGIS to analyze global spatial correlations. This analysis was further enhanced by visualizing the local spatial correlation characteristics.

According to Table 5, the autocorrelation coefficients of land intensive use levels in the three prefecture level cities in Northeast China in 2010, 2015, and 2020 were all positive, and the P-values passed the significance test of 0.5, indicating a significant positive correlation in space. The correlation experienced a wave of first increasing and then decreasing, and there was a significant agglomeration effect overall in space.

Table 5: Global Spatial Autocorrelation Analysis Results of Coupling Coordination Degree in Northeast China. Source: Self Drawing.

Year	Moran's I	z	p
Land Intensive Use Level in 2010	0.177413	2.005981	0.044858
Land Intensive Use Level in 2015	0.276764	2.963194	0.003045

Land Intensive Use Level in 2020	0.212536	2.354618	0.018542

Further analysis of local spatial autocorrelation revealed that, similar to the level of land intensive use, the coupling and coordination level between the two systems remained concentrated in the southeastern region of Liaoning Province, with the regional scope gradually shrinking. But over time, the cold spot area has undergone significant changes. In 2010, only Daqing City was a cold spot city, and there were no prominent cold spot cities in 2020. The reason for this may be that the overall coupling and coordination levels in Heilongjiang Province and Jilin Province are relatively low, and the coupling and coordination levels in each prefecture level city are relatively close. Overall, the coupling coordination degree of the three provinces in Northeast China is relatively low and the development is slow. Most cities are still limited by the level of land intensive use and are in a stage of low coupling level.

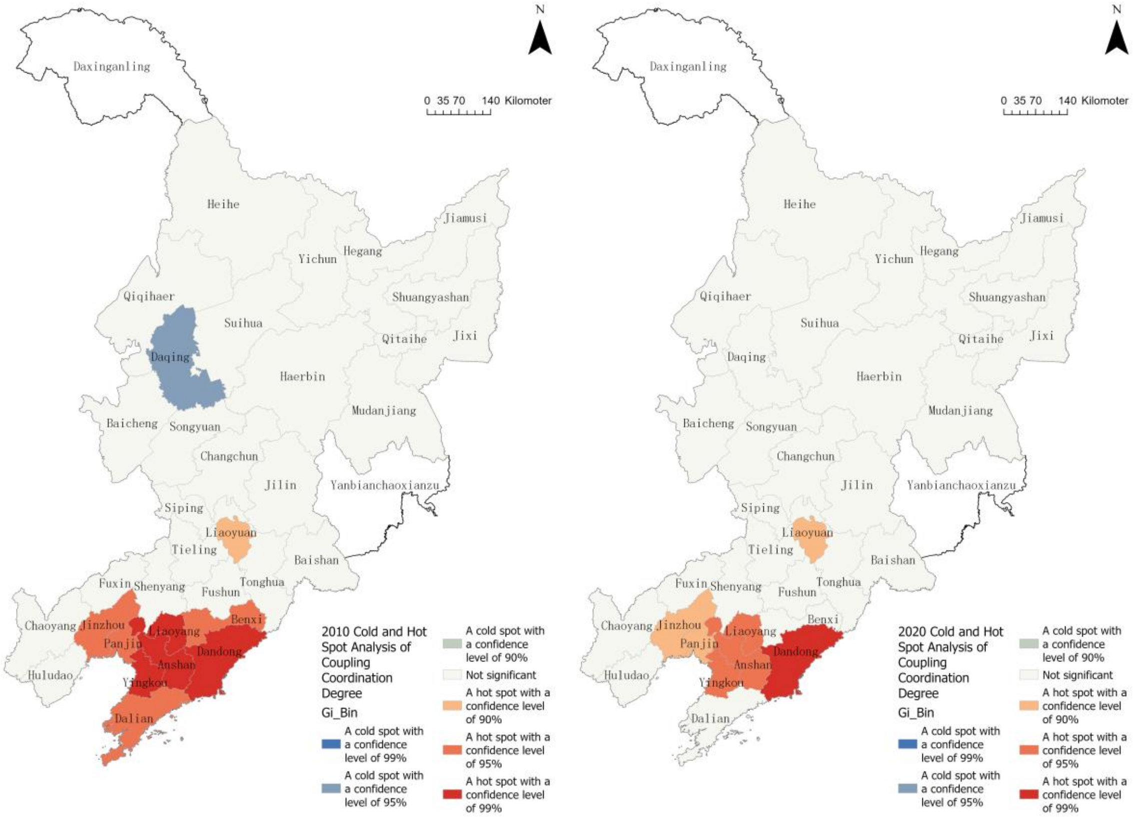

Figure 6: Cold and Hot Spot Analysis of Coupling Coordination Degree in Northeast China for the Years 2010 and 2020. Source: Self Drawing.

6. Conclusions and Discussion

This study first evaluates the land intensive use levels in the prefecture-level cities of Northeast China. Building on this evaluation, we measure the coupling coordination relationship between land intensive use and sustainable development. Empirical analysis is conducted using methods such as the entropy method, coupling coordination degree model, and geographic spatial analysis. The research conclusions are as follows:

(1) Over the past decade, there has been no significant improvement in the land intensive use levels in Northeast China. The patterns of land intensive use closely align with the spatial distribution identified in

urban shrinkage. All cities with low land use intensity are shrinking cities, while cities with higher levels of land intensive use are non-shrinking. Moreover, shrinking cities are experiencing a regression in their land intensive use levels.

(2) There is a significant spatial correlation in the land intensive use levels across Northeast China, exhibiting a pronounced core-periphery characteristic. Regions with higher land intensive use levels are predominantly distributed along the Harbin-Dalian axis, displaying a distribution pattern of higher values in the south and east and lower values in the north and west.

(3) The relationship between land intensive use and sustainable development in Northeast China remains in the antagonistic stage, with overall development progressing slowly. The region has yet to transition from a state of imbalance and decline to one of coupling and coordination. The coupling degree of the systems significantly exceeds the coordination degree, and the interaction between the two maintains a long-term high coupling—low coordination imbalance, particularly pronounced in shrinking cities.

(4) The number of cities in the three northeastern provinces that have reached the stage of integration between intensive land use and sustainable development is gradually increasing, while the number of cities in the low coupling stage is gradually decreasing, and the number of cities in the antagonistic stage is the highest. There is significant spatial heterogeneity, and the coupling and coordination degree of cities distributed along the Harbin Dalian axis is generally high. The spatial characteristics generally show a gradual decrease from the Harbin Dalian axis to the east and west.

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